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STATE OF WASHINGTON DEPARTMENT OF ECOLOGY
SOURCE TEST METHOD 19

PARTICLE SIZING USING A CASCADE IMPACTOR

1. Principle

Particles are size fractionated by drawing stack gas through a series of progressively smaller holes or jets increasing their velocity. Particles with the required inertia will cross gas streamlines and impact onto collecting plates. Particles with less inertia will not be impacted and will be carried by the air stream to the following stage. Since the jet velocities increase as the jet size decreases, progressively smaller particles are impacted and retained as they travel through the impactor and a classification results.

2. Description

The cascade impactor is placed inside the stack at a representative location. An isokinetic sampling rate is determined and sampling takes place at that same rate throughout the sample period. Particles are collected on a suitable lightweight collection surface (substrate), and the weight determined. The volume sampled is determined by a totalizing dry gas meter. A cumulative frequency size distribution is calculated and the mass mean diameter found. The mass distribution may also be determined.

3. Equipment

The cascade impactor can be attached to a commercial model Method 5 particulate train or to a variety of individual arrangements which must include a vacuum pump, dry gas meter, condenser, probe tube and impactor. An example of this is shown in Figure 1. The basics of a cascade impactor are shown in Figure 2.

a. Substrates - generally metal foil or glass fiber. Metal foils may be greased depending on conditions. Apiezon H and Hercules Industrial Spray Silicone have been found to be stable at temperatures up to 350°F. Glass fiber surfaces may be used but, depending on the particulate, may cause increased collection due to particle penetration and retention giving mass mean diameters 30 percent greater than using grease coated substrates.

b. Nozzles - straight tapered nozzles with no bends. Button hook nozzles are not acceptable. The minimum size is 3/16 inch in diameter.

c. A heated probe capable of maintaining a minimum gas temperature above the dew point, downstream of the impactor to prevent condensing moisture from entering the impactor. An unheated probe inclined to force moisture to flow away from the stack is acceptable.

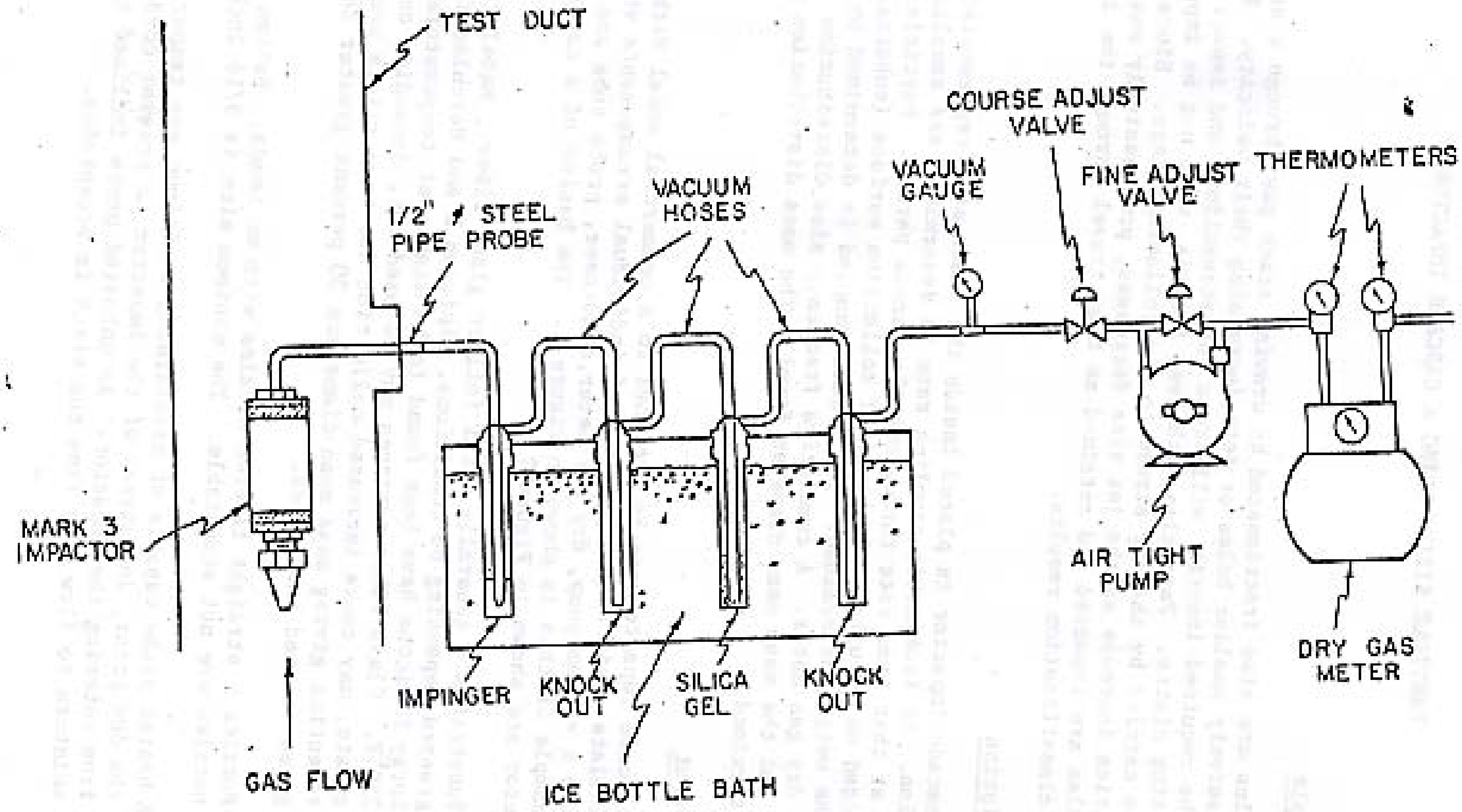

Fig. 1 UW MARK 3 CASCADE IMPACTOR SAMPLING TRAIN

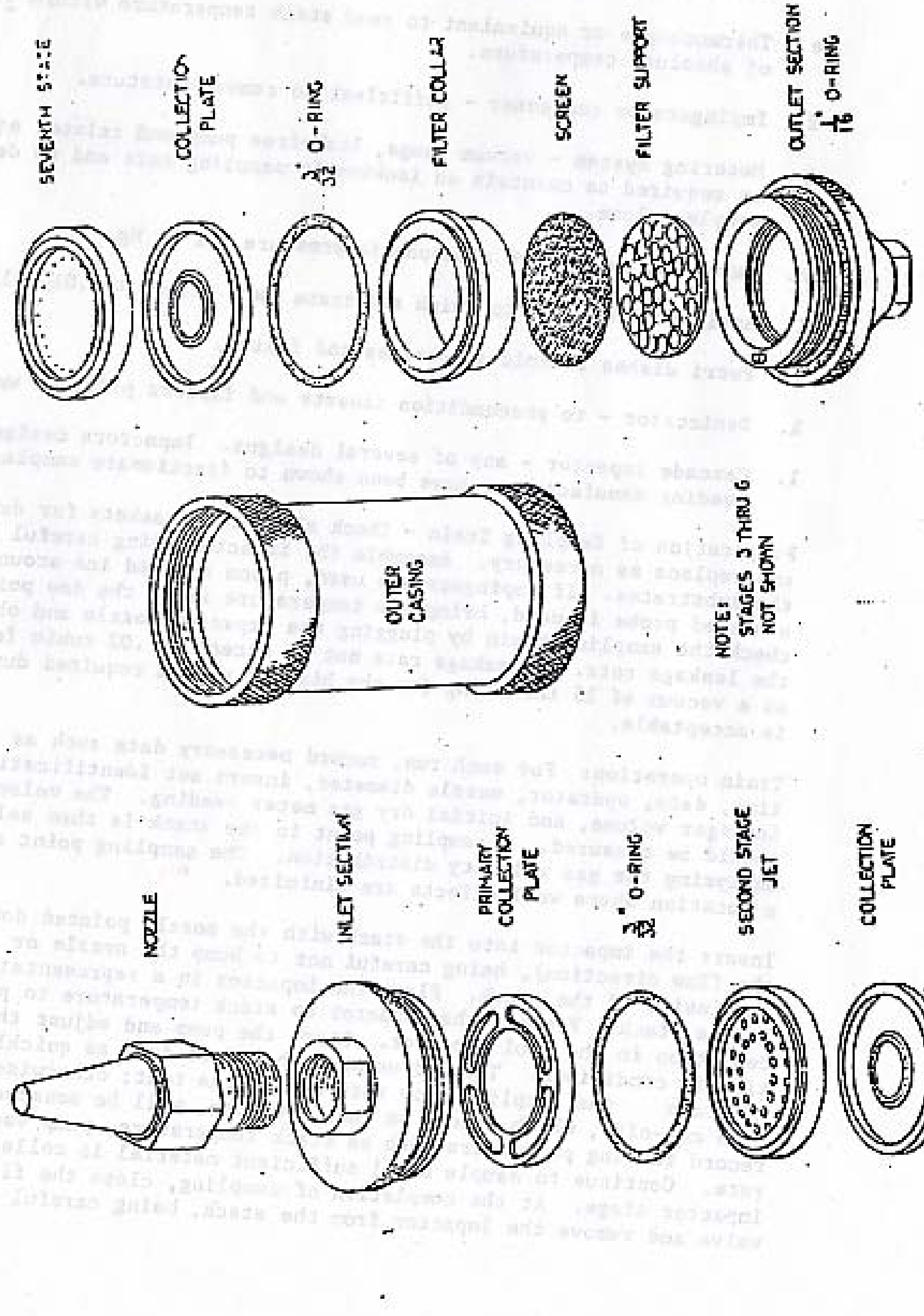

Fig. 2 Expanded View of Mark 3 Cascade Impactor

d. Pitot tube - types S, or equivalent, with coefficient within $\pm 5\%$ over the working range.

e. Thermocouple or equivalent to read stack temperature within $\pm 1.5\%$ of absolute temperature.

f. Impingers or condenser - sufficient to remove moisture.

g. Metering system - vacuum gauge, leak-free pump and related equipment as required to maintain an isokinetic sampling rate and to determine sample volume.

h. Barometer to measure atmospheric pressure $\pm .1$ in Hg.

i. Analytical balance to weigh substrate and filter to .01 milligrams.

j. Petri dishes to hold substrates and filter.

k. Desiccator - to precondition inserts and filters prior to weighing.

l. Cascade Impactor - any of several designs. Impactors designed by leading manufacturers have been shown to fractionate samples efficiently.

Preparation of Sampling Train - Check all O-ring gaskets for deformities and replace as necessary. Assemble the impactor being careful not to touch the substrates. If impingers are used, place crushed ice around them. If a heated probe is used, bring the temperature above the dew point. Leak-check the sampling train by plugging the impactor nozzle and observing the leakage rate. A leakage rate not in excess of .02 cubic feet per minute at a vacuum of 15 inches Hg (or the highest vacuum required during sampling) is acceptable.

Train operation: For each run, record necessary data such as location, time, date, operator, nozzle diameter, insert set identification, initial impinger volume, and initial dry gas meter reading. The velocity profile should be measured. A sampling point in the stack is then selected after analyzing the gas velocity distribution. The sampling point should be in a location where wall effects are minimized.

Insert the impactor into the stack with the nozzle pointed downstream (in the flow direction), being careful not to bump the nozzle or scrape it on the inside of the stack. Place the impactor in a representative location in the stack. Preheat the impactor to stack temperature to prevent condensation in the cool impactor. Start the pump and adjust the flow to isokinetic conditions. This adjustment should be done as quickly as possible. Maintain the sampling flow rate during the test; otherwise, the particle size cut-offs, which depend on the flow rate, will be smeared. Periodically record testing parameters such as stack temperature, pump vacuum and flow rate. Continue to sample until sufficient material is collected on each impactor stage. At the completion of sampling, close the flow control valve and remove the impactor from the stack, being careful not to bump it.

It has been shown that a major part of wall losses are due to migration of particles (after impaction) caused by the jostling around of the impactor during removal from the duct or stack, and transportation to the laboratory.

Sample Recovery: Remove the collection substrates from the collection stages and place them in marked petri dishes. Brush all particulate matter from the interior surfaces of each stage and the nozzle to the immediately downstream collection surface. The exposed substrate should form discreet, well-defined piles. Re-entrainment should be suspected if the piles are non-uniform, diffuse, halo like, or there are dust trails leading from the sample deposits to the orifices. The backside of the jet plates may have collected losses which have bounced from the substrates.

4. Analysis

Dry the inserts to a constant weight. The use of a balance with an accuracy of .01 mg is preferable. In some cases 0.1 mg. sensitivity is acceptable. If impingers are used, determine moisture content by measuring condensate volume and the silica gel weight gain.

5. Calculations

Calculate the change in weight of the substrates and backup filter. Add the differences to get the total particulate weight collected. Divide the amount collected on each substrate by the total amount collected to find what percent of the total is impacted on each substrate. Find the D_{50} for each stage by use of the supplied calibration graphs for the impactor or by direct use of equations. The equivalent aerodynamic particle size should be presented as a minimum, using the assumption of unit particle density. The particle size may also be found by using handbook values for the density of the substance if known. Graph the results on log probability paper with particle diameter (d_{50}) versus cumulative percent by weight.

The data should be examined for inconsistencies. For example, there should be a minimum .3 mg. collected on each stage and a maximum of 5 – 7 mg. If the filter has an unusually high weight in comparison to the preceeding stages, re-entrainment should be suspected. Some equations that can be used to find the D_{50}, the particle diameter at which the stage achieves 50 percent efficiency, are shown below:

$$D_{50} = \left(\frac{2.05 \; u \; D_j^{\,3} \; X_j \; P_j}{C \; \rho_p \; Q_s \; P_s} \right)^{1/2}$$

Where:

$$C = 1 + \frac{2L}{D_{50}} \left(1.23 + 0.41 \; e \times p \; \frac{(-0.44 \; D_{50})}{(L)}\right)$$

D_{50} = Diameter of particle impacting on the stage, cm.

D_j = Jet diameter on stage, cm

X_j = Number of jets on stage.

ρ_p = Density of particles, g/cm^3

P_j = Pressure on stage, mm Hg.

Q_s = Volumetric flow rate through impactor at stack conditions, cm^3/sec.

P_s = Stack pressure, mm Hg

L = Mean free path, cm

$$= 8.572 \frac{u}{P_j} \frac{Tj}{MW}$$

u = Viscosity at stage

MW = Molecular weight of gas stream

Tj = Temperature at stage